

# Meteorite Hills 01210

Anorthosite-bearing basaltic fragmental breccia  
22.8 g



*Figure 1: Meteorite Hills (MET) 01210 as found in the bare ice in 2002.*

## **Introduction**

Meteorite Hills (MET) 01210 was found in the Meteorite Hills region of Antarctica on December 23, 2001 (Figs. 1-3). It has roughly 30% black shiny fusion crust, and contains many white and brownish mineral and lithic fragments. These two types of clasts are an indicator of its chemical composition – that of a mingled meteorite, despite its original classification as a feldspathic regolith breccia.

## **Petrography and Mineralogy**

MET 01210 is a polymict regolith breccia (Fig. 4 to 6) containing mineral clasts of plagioclase feldspar, pyroxene, olivine, ilmenite, and metal, and lithic clasts of coarse-grained basalt/gabbro, feldspathic clasts, granulites, and symplectites (Figs. 7 to 11; Arai et al., 2005; Joy et al., 2006; Zeigler et al., 2005; Day et al., 2006). Olivine and plagioclase mineral clasts are more fayalitic and sodic, respectively, suggesting a basalt origin rather than highlands (Joy et al., 2006). The amount of basaltic and highlands materials in MET 01210 has been estimated at 68% basaltic by Arai et al. (2008) based on mixing calculations. Huber and Warren (2004) argue for the presence of more finely exsolved pyroxene in MET 01210 than other Apollo basaltic rocks (Fig. 8). This may indicate a slower cooling history for some of the materials within this sample. Detailed minor and trace element measurements for individual phases have been reported by Day et al. (2006), but are not tabulated here.

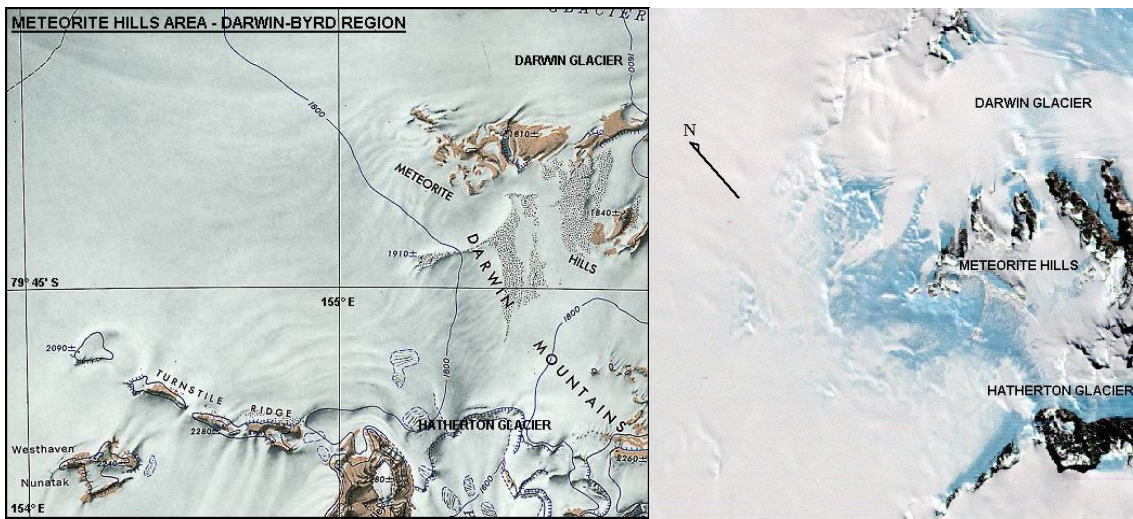


Figure 2: Map of the Meteorite Hills region of Antarctica in the upper right corner of the region. Figure 3: Satellite image of the Meteorite Hills region, at a slightly different orientation than Figure 2 - Turnstile Ridge, oriented horizontally in lower left of Figure 2, is rotated counterclockwise approximately 45 degrees in Figure 3.

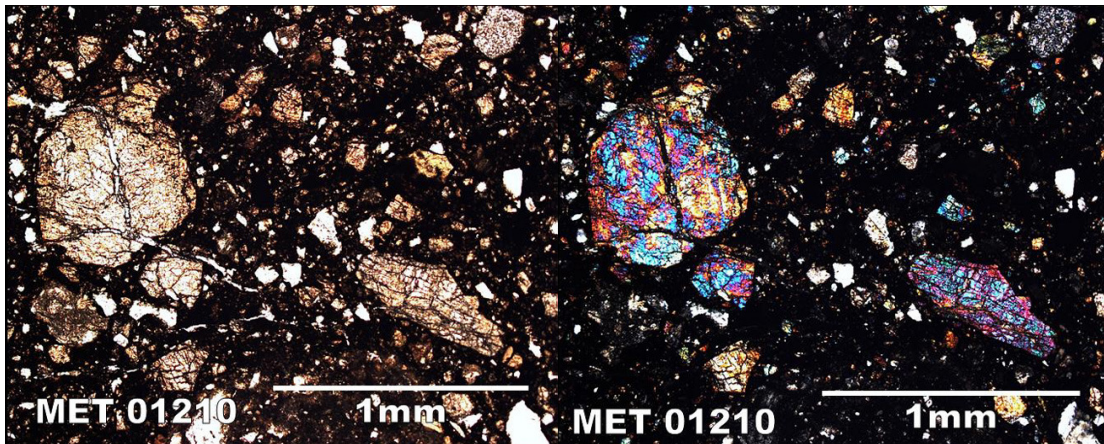


Figure 4: plane polarized (left) and crossed nicols (right) views of section ,4 of MET 01210, showing pyroxene-rich clasts in a dark breccia matrix.

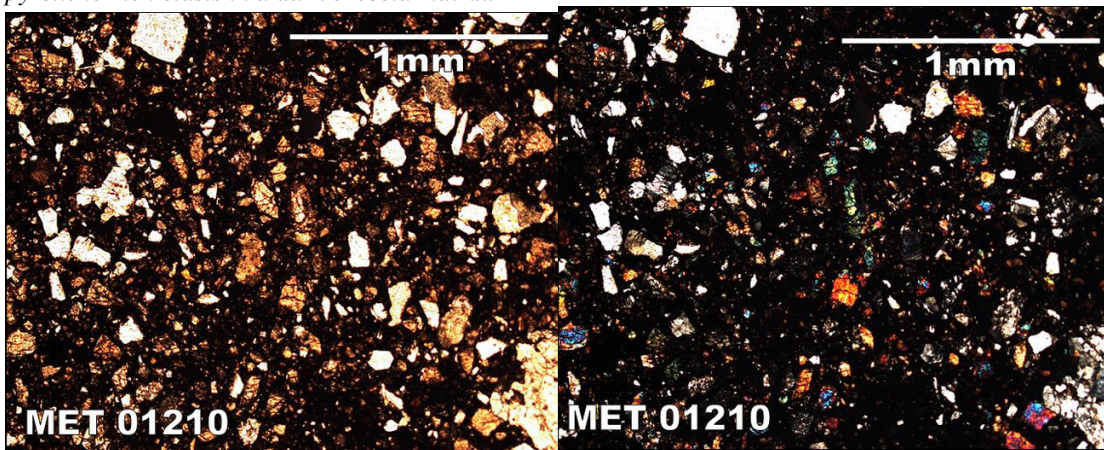


Figure 5: plane polarized (left) and crossed nicols (right) views of a different region of section ,4 of MET 01210, showing a mixture of pyroxene-bearing and feldspathic clasts in a dark breccia matrix.

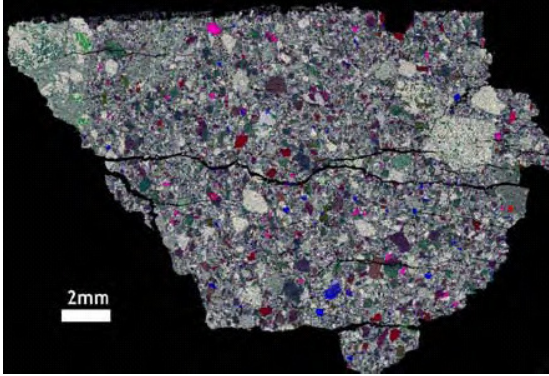
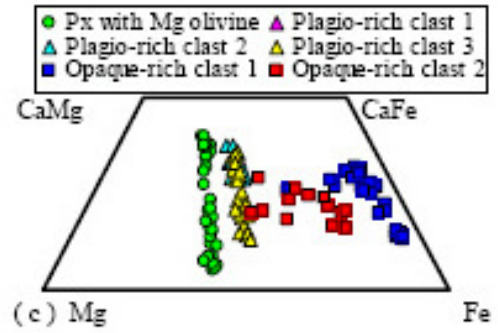
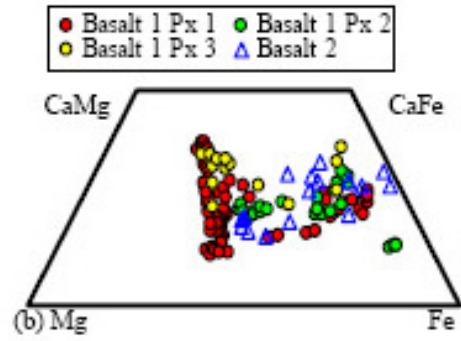
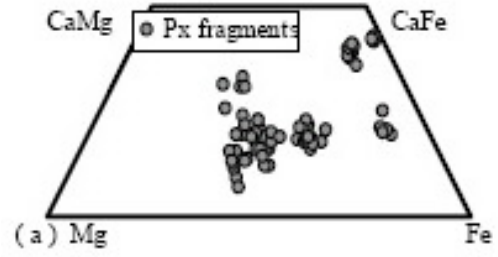


Figure 6: Elemental map of MET 01210 ,27 (from Joy et al., 2006), showing Si as blue, Al as white, Mg as green, Fe as red, Ca as yellow and Ti as pink. Both aluminous and basaltic clasts can be identified on this basis.



← Figure 7: Compositional variation observed in pyroxenes from MET 01210, in basaltic and feldspathic clasts (from Arai et al., 2005).

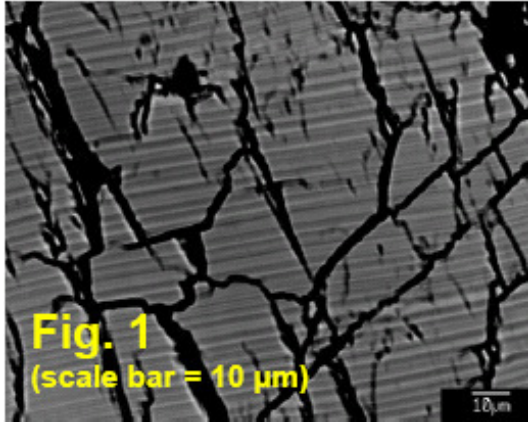


Figure 8: Very fine exsolution lamellae in pyroxene from MET 01210 from the study of Huber and Warren (2004).

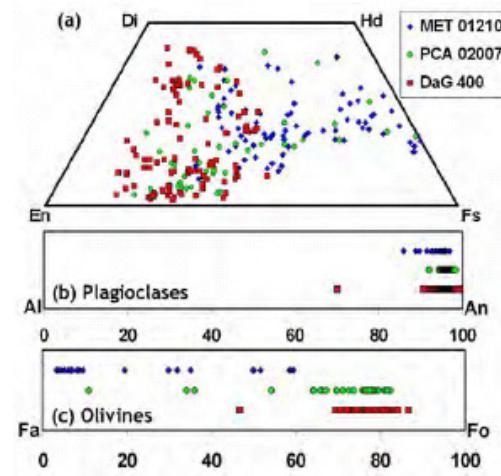
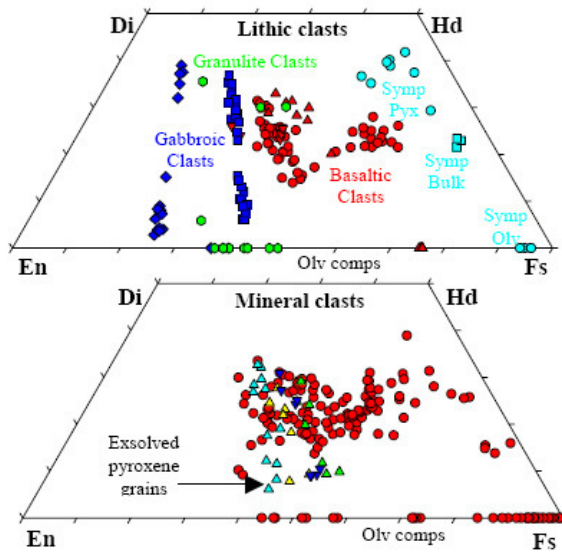


Figure 9: Compositional range of pyroxenes from lithic and mineral clasts MET 01210, 20 (from Zeigler et al., 2005).

Figure 10: Compositional range of pyroxenes from lithic and mineral clasts MET 01210, 27 (from Joy et al., 2006).

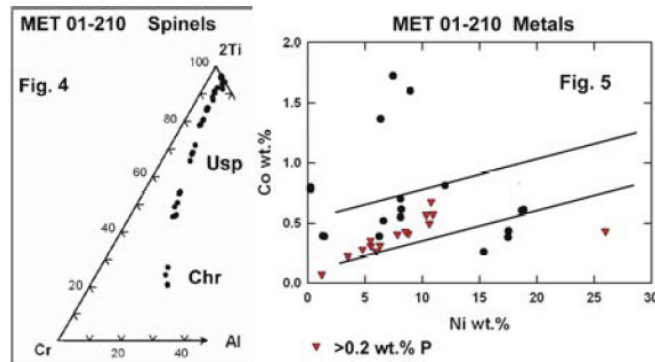


Figure 11: Compositional range of spinel from a gabbroic clast and metals from the matrix in MET 01210, 18 (from Patchen et al., 2005).

## Chemistry

The mingled petrography of MET 01210 is born out by its chemical composition which is intermediate between mare and highlands end members (Fig. 12; Table 1). For example, CaO and FeO are ~ 15 wt% and ~ 16 wt%, respectively. MET 01210 contains more TiO<sub>2</sub> than other basaltic meteorites (1.6 to 2.0 wt%), which is also a reflection of the clasts within – they are of low Ti derivation as opposed to the very low Ti derivation of many of the other basaltic meteorites (e.g., Yamato 98169, QUE 93169, or EET 87521). In addition, the low  $\mu$  source region calculated for basaltic clasts in MET 01210 defined by U-Pb studies (Terada et al., 2007) is different from the relatively high  $\mu$  source characterized from Apollo basalts, and puts MET into a small group of basaltic lunar meteorites which have this chemical distinction in common (Terada et al., 2007).

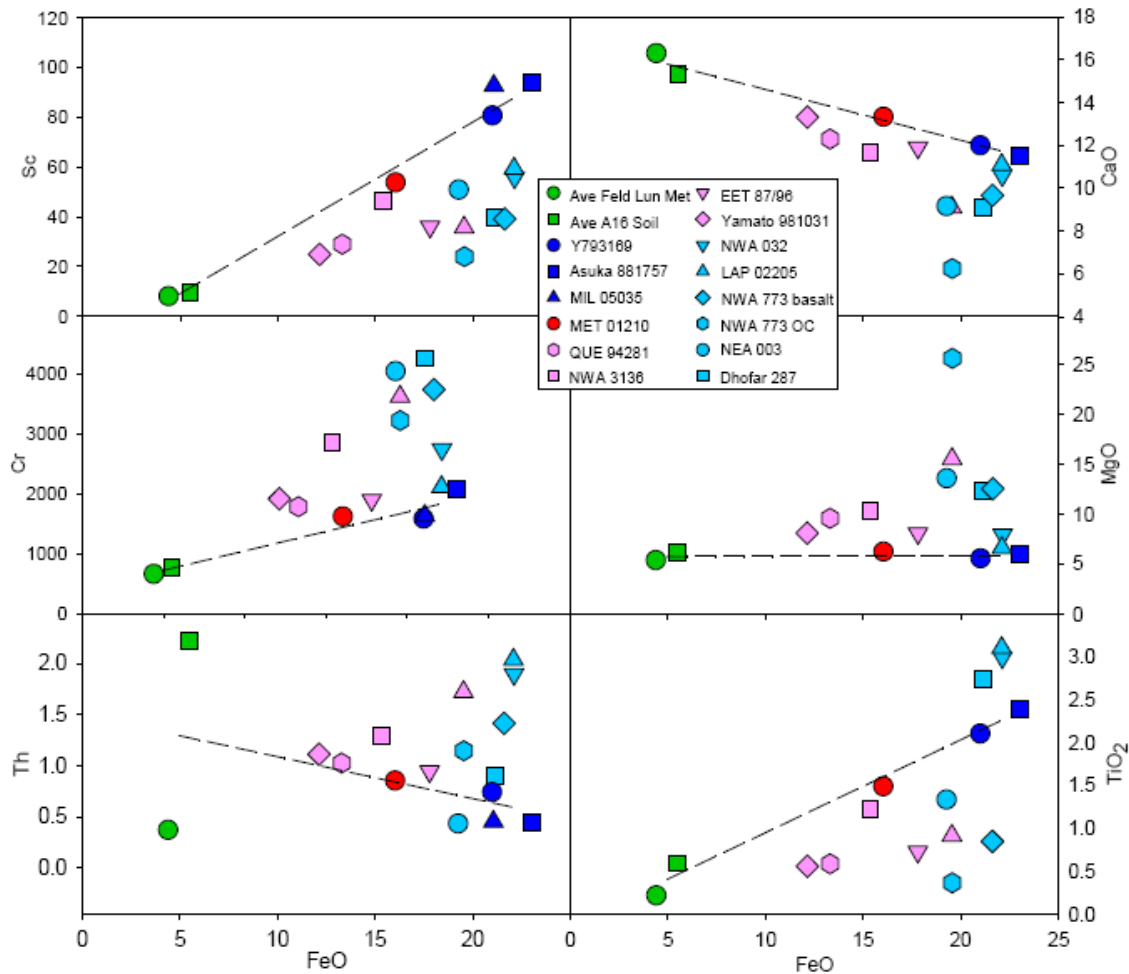


Figure 12: FeO, CaO and Th contents of MET 01210 compared to several other mingled lunar meteorites (pink) as well as mare (blue) and highlands (green) meteorites and soil (from Zeigler et al., 2007). The dashed line is a mixing line between the average composition of A88 and Y79 and an average of Apollo 16 soils and feldspathic lunar meteorites. In every case, MET falls on or very near this mixing line, suggesting that MET is composed primarily of A88/Y79 basalt (~65%), that has been diluted by some moderately ITE-enriched (relative to feldspathic lunar meteorites) feldspathic component.

**Table 1a. Chemical composition of MET 01210**

<i>reference</i>	1	2	3
<i>weight</i>	fc		fc
<i>method</i>	d	a,b	b
SiO <sub>2</sub> %	44.8	44.03	44.8
TiO <sub>2</sub>	1.58	1.55	1.64
Al <sub>2</sub> O <sub>3</sub>	17	16.6	16.2
FeO	16.2	16.46	16.9
MnO	0.26	0.22	0.24
MgO	5.97	6.2	6.5
CaO	13.6	12.96	13
Na <sub>2</sub> O	0.26	0.32	0.28
K <sub>2</sub> O		0.06	0.06
P <sub>2</sub> O <sub>5</sub>		0.05	0.24
S %			
<i>sum</i>			
Sc ppm		56	
V		60	
Cr	1300	1881	
Co		32	
Ni		212	
Cu		23	
Zn		37	
Ga		19.1	
Ge			
As			
Se			
Rb		1.34	
Sr		163	
Y		37	
Zr		103	
Nb		1.07	
Mo			
Ru			
Rh			
Pd ppb			
Ag ppb			
Cd ppb			
In ppb			
Sn ppb			
Sb ppb			
Te ppb			
Cs ppm		0.089	
Ba		81	
La		6.69	
Ce		13.8	
Pr		2.12	
Nd		10.7	

Sm	3.58
Eu	1.11
Gd	4.54
Tb	0.905
Dy	5.85
Ho	1.26
Er	3.63
Tm	0.532
Yb	3.54
Lu	0.519
Hf	2.37
Ta	0.103
W ppb	
Re ppb	
Os ppb	
Ir ppb	
Pt ppb	
Au ppb	
Th ppm	0.855
U ppm	0.321

*technique (a) ICP-AES, (b) ICP-MS, (c ) IDMS, (d) EMPA*

**Table 1b. Light and/or volatile elements for MET 01210**

Li ppm	8
Be	1.72
C	
S	
F ppm	
Cl	
Br	
I	
Pb ppm	0.551
Hg ppb	
Tl	0.009
Bi	

1) Zeigler et al. (2005); 2) Joy et al. (2006); 3) Day et al. (2006)

### **Radiometric age dating**

The U-Pb ages of phosphates (merrillite and apatite) in basaltic clasts from MET 01210 are 3.8 to 3.9 Ga (Fig. 13), similar to the old ages determined for Asuka 881757, Yamato 793169, and Miller Range 05035 (Terada et al., 2007).

### **Cosmogenic exposure ages**

Studies of MET 01210 so far have determined  $^{10}\text{Be}$  and  $^{36}\text{Cl}$  ages of 0.95 Ma and 0.90 Ma, respectively (Nishiizumi et al., 2005, 2006), and a terrestrial exposure age of < 20 Ka. The similarity of petrography, composition and exposure ages led Arai et al. (2005) to suggest that Asuka 881757 and Yamato 793169 are launch paired with MET 01210. This has been extended to include MIL 05035, Arai et al., 2008, who propose a

cryptomare origin for these meteorites – maybe the Schiller-Schickard region near the SW limb.

### Processing

MET 01210 was not initially recognized to be lunar, and thus was processed together with many smaller meteorites from the 2001-2002 season (Fig. 14). Later processing has been extensive and close to 20 splits and sections have been sent out to individual scientists (Figures 15-21; Table 2).

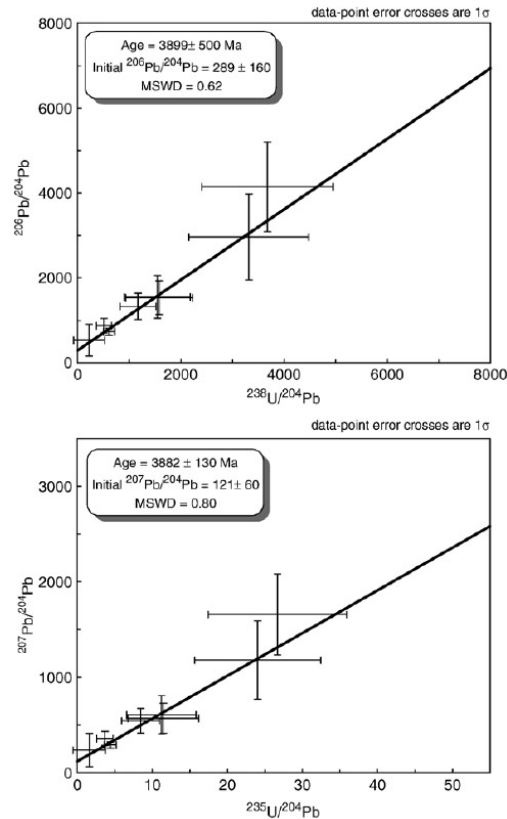


Figure 13: U-Pb ages of phosphates from a basaltic clast in MET 01210 (Terada et al., 2007).

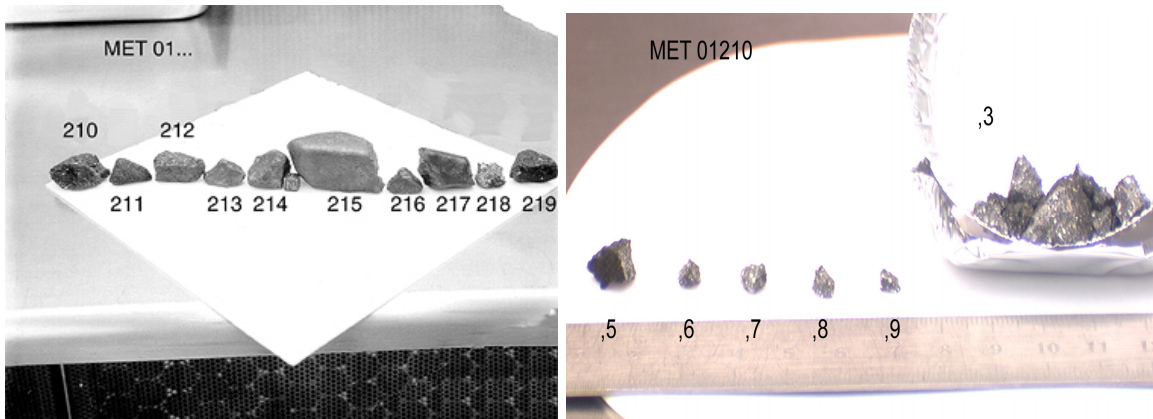


Figure 14: Initial processing photo of MET 01210 in the Meteorite Processing Laboratory of NASA-JSC. Figure 15: Splits 3 through 9 of MET 01210.

MET 01210,0



Figures 16 to 21: Main mass (,0) and Splits 11 through 15, 22, 23, and 25 of MET 01210.

Table 2. Allocation history of MET 01210 (March, 2008)

split	TS	parent	mass	PI/location	comment
0		0	11.578	JSC	Documented chip
1		0		Entirely subdivided	Potted butt
	2		0.01	McCoy/SI	Thin section

	17		0.01	Warren	Thin section
	18		0.01	Taylor (LA) / JSC	Thin section
	19		0.01	Arai	Thin section
	21		0.01	Russell	Thin section
	27		0.01	Russell	Thin section
	28		0.01	Warren / JSC	Thin section
3		0	1.974	JSC	Chips and fines
5		3	0.479	JSC	Potted butt
	20		0.01	Korotev	Thin section
6		3	0.111	Busemann	Interior chip
7		3		Arai	Interior chip
8		3		Herzog	Interior chip
9		3		Korotev	Interior chip
11		0		Nishiizumi	Exterior chip
12		0		Nishiizumi	Interior chip
13		0		Korotev	Interior chip (E face)
14		0		Korotev	Interior chip (W face)
15		0		JSC	Chips and fines
22		3	1.447	JSC	Potted butt
	29		0.01	Taylor (GJ) / JSC	Thin section
	31		0.01	Terada	Thin section
	34		0.01	Righter	Thin section
23		3	0.531	Warren	Interior chips
25		15	0.264	Russell	Interior chips
32		3	0.084	Podosek	Interior chip

*K. Righter, 2008*